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The confluence of intrinsic and extrinsic constraints on 3- to 9-month-old infants' catching behavior

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Abstract

The present study sought to uncover what constraints shape the early development of the perceptual–motor skill of catching, and how intrinsic (i.e., movement possibilities) and extrinsic constraints (i.e., object speed imposes temporal precision) impinge on the perception of whether or not a moving object affords catching. Thirty-five infants (with different preferred catching tendencies) between 3 and 9 months of age were presented with balls approaching from the side with different speeds. Video recordings were used to determine how each infant reached for the ball (with the right hand, the left hand or with both hands) and whether these catching attempts were successful (resulting in ball–hand contact). The lower the proportion of failing catching attempts the more accurate the infant perceived the ball's catchability. This accuracy is also reflected in the discrepancy between boundary and success speed (i.e., the difference between the ball speed that still was perceived as catchable and the highest ball speed that was actually successfully managed). The findings indicate that the interaction between infants' intrinsic constraints (which gave rise to, e.g., the preference for two-handed catching and inclination to reach) and the extrinsic constraints (imposed by object speed) induces age-related differences in catching performance and age-related differences in the perception of what action a moving object affords.

Keywords: Constraints; Catching; Affordance; Staircase design

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1. Introduction

In the course of development, infants learn to tune their actions to what they perceive. For the developmentalist, an important issue is to uncover the constraints that contribute to the emergence of appropriate perceptions and actions, and how these constraints interact. Actions must become attuned to perceptual information about the infants' selves and their surroundings. Also, before acting an infant must discover what actions can be actualized. Acting in response to moving objects implies that the infant has already discovered that the object can be acted upon. For instance, that it can be grasped or avoided. What affordance or action opportunity the infant perceives and what action the infant intends to perform is constrained both by the environment and the infant's action system (Gibson, 1979; see also Chemero, 2003). An example of an extrinsic constraint on the development of the perception of an affordance is the size of an object; a small moving object may afford catching, whereas an object too large to be easily grasped may afford avoidance behavior. This example also illustrates the confluence of extrinsic and intrinsic constraints. That is, constraints inherent in the infant, such as movement possibilities, influence perception of what actions the environment has to offer (also called movement potential). The infant will only perceive that an object is catchable if he or she has already mastered some control over his or her arm movements (Yonas et al., 1977). Thus, the perception of what objects, events and persons in the infant's surroundings afford is likely to be supported by an expansion of the movement possibilities.

However, once an affordance is perceived, it is not necessarily acted upon optimally at once; an infant's first attempts are often inefficient and unsuccessful. Recently, we have demonstrated that the degree to which infants can control their movements is an important intrinsic constraint in the development of the perception of what a moving object affords for action. Specifically, it was observed that 6- and 7-month-old infants were fairly accurate in perceiving whether a frontally approaching object could be caught or if it was moving too fast to be caught (Van Hof, Van der Kamp, & Savelsbergh, 2005). Younger infants, however, frequently misperceived whether or not an object could be caught. They kept trying to catch, irrespective of whether their attempts were successful, whereas 6- to 7-month-olds refused to reach for objects that moved too fast to be caught. An important constraint on these infants' perception of catchability was shown to be their information-based control of catching. That is, improvements in perception of catchability coincided with the establishment of a more appropriate information–movement coupling to satisfy the extrinsic constraints. Unlike the younger infants, the 6- to 7-month-olds used more appropriate optic variables to control the temporal characteristics of the catching movement. We concluded, therefore, that the development of the perception of the affordance of catchability is closely associated with the development of the visual control of catching movements (i.e., selecting the more useful optic variable).

A striking observation in the Van Hof et al. (2005) study that may not have received sufficient attention was the predominance of right-handed catching attempts. None of the infants crossed the midline while trying to catch the approaching ball. This is in agreement with previous observations that infants prefer to reach with one hand for relatively small balls (e.g., Van Hof, Van der Kamp, & Savelsbergh, 2002). In addition, it takes more time to enter the interception area with the left hand than with the right hand (see Fig. 1; left panel). Hence, it may have been the extrinsic constraints upon the space and time in which the arm movement should be executed that induced the predominance of one (right)-handed catching.

In the case of an object approaching from the side, these extrinsic spatio-temporal constraints on catching are partly alleviated. The ball's trajectory increases the interception area (see Fig. 1; right panel)

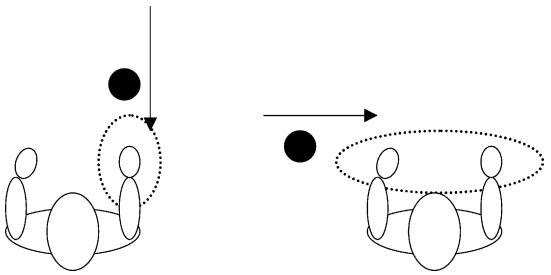

Fig. 1. Object approaching frontally (left) and object moving laterally (right). Dashed circles indicate the area of interception.

and offers the infant more time to successfully perform the catch. Besides, the larger interception area allows additional catching styles, or, in other words, it enhances the infant's movement potential. In this situation, also left-handed and bimanual catching attempts are likely to result in a successful interception. Von Hofsten (1980) suggested that infants adopt a catching style that satisfies the extrinsic constraints. He made this suggestion on the basis of observations of 18- to 36-week-old infants who were required to catch an object that moved from the side with various velocities ranging from 3 to 60 cm/s (Von Hofsten, 1980), similar to the situation depicted in Fig. 1 (right panel). Object speed affected the way infants attempted to intercept the object. Low approach velocities induced bimanual and right- and left-handed catches. Fast-moving objects, however, often induced contralateral catches (i.e., right-handed in Fig. 1; right panel). Von Hofsten argued that by doing so infants created more time to reach for the moving object, which is most opportune for high velocities. This pattern was most pronounced in the youngest infants suggesting that the need to create more time decreases with age. The manner infants dealt with the extrinsic constraints changed with age, as reflected in the changed catching tendencies. What remains unclear, however, is whether the shifting dominance of catching style also influences the development of the perception of catchability. Therefore, we asked how catching style constrains the accuracy of 3- to 9-month-old infants' perception of catchability of objects that approach at different speeds.

To examine this, 3- to 9-month-olds were presented with balls that approached from the left (Fig. 1; right panel). A modified staircase method was used to establish the infants' accuracy of perceiving whether an object moved too fast to be caught or not. We also determined whether the infants caught the ball with the left, the right or with both hands. Although these three catching styles may all lead to successful interception, they are not equally effective. Each catching style seizes a separate but overlapping part of the ball's trajectory. Catching styles can be coarsely divided in terms of the spatio-temporal constraints they bring about. The one-handed reaches can cover a larger area of the ball's trajectory than the bimanual reaches, both in time and space. Hence, the required temporal precision is lower for the one-handed attempts, that is, the time gap in which the infant can seize the ball is larger for one-handed catching than for bimanual catching. Furthermore, the interception area of the left hand is of the same size as that of the right hand, but the time it takes for the object to enter the right-hand's interception area is longer since in each trial the object travels the same distance from left to right (see also Fig. 2). Therefore, the temporal constraints are smallest for right-handed reaches, that is, right-handed catching offers the most time to look at the object, and to plan and execute the catch.

The infants' movement potential (that is, the catching styles that can be realized) might be limited by the developmental phase in which they are. That is, young infants that are beginner reachers predominantly reach for stationary objects with both hands (Corbetta & Thelen, 1996). Around the time when infants

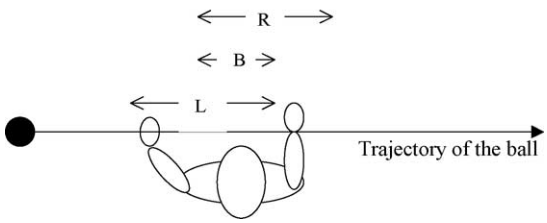

Fig. 2. Schematic top view of experimental set-up. The size of the left hand's interception area equals that of the right hand, whereas bimanual reaches seize a smaller area. In addition, since the ball travels the same distance from left to right each trial, catching with the right hand offers the most time to plan and execute the catch.

begin to sit independently, that is, when they are about 6- to 8-months old (Gesell & Ames, 1940; McGraw, 1945), there is a change from mainly bimanual arm movements to an increase in the number of one-armed reaches (Rochat, 1992). However, older infants can return to two-handed reaching when they are learning new actions, such as walking (Corbetta & Bojczyk, 2002). Therefore, changes in intrinsic constraints might influence the infants' preferences for a particular reaching style.

Do infants also show these preferences when additional extrinsic constraints are imposed? When having infants reach for moving objects it was anticipated that each infant will try to satisfy the temporal constraints. In doing this, the preferred reaching style might count as a benchmark in tackling the additional temporal precision demands. Therefore, it was expected that different object speeds will induce different catching styles. However, this relation may be mediated by the degree to which the infant has mastered control of the arm movements and the intrinsic preferences in catching style. Further, we hypothesized that not only catching style is determined by the confluence of intrinsic and extrinsic constraints but also perceptual judgments of the object's catchability. It was expected that as infants are more proficient in adapting their catching style to the task requirements, they will be more accurate in perceptually differentiating balls that are catchable from those that are not.

2. Method

2.1. Participants

Fifty-five full-term, healthy infants between 3 and 9 months of age participated in the experiment (see for group characteristics Table 1). These were the same infants as in Van Hof et al. (2005). Five infants did not complete the experiment due to fussing or crying and 15 infants were excluded from the analyses because they did not attempt to reach. We distinguished three groups: infants younger than 5 months of

Table 1
Participants characteristics

Group	Averaged age (weeks)	Range (days)	Number of infants
3- to 5-month-olds	18.03	93–161	31
6- to 7-month-olds	28.90	181–222	11
8- to 9-month-olds	37.15	241–279	13

age, infants between 6 and 7 months of age and infants older than 7 months of age (cf. Van Hof et al., 2005). This resulted in 15 infants in the 3- to 5-month-old group, 10 infants in the 6- to 7-month-old group and 10 infants in the 8- to 9-month-old group. Before the experiment, the infants' parents gave their written informed consent to participate.

2.2. Apparatus

A bright yellow ball with a clown's face painted on it (4.5 cm in diameter) was presented by the Ball Transport Apparatus (see, for details, Van Hof et al., 2005). A polystyrene rod (80 cm × 2 cm × 2 cm), at the end of which the ball was attached using a small magnet, was moved from left to right side and the ball passed the infant within reaching distance at shoulder height. When the infant did not reach for the approaching ball, the ball continued on a fixed spatial trajectory in front of the infant to the right (see Fig. 1; right panel). Infants were sitting in a special baby chair, with the trunk straight, the head upright and the limbs free to move. Each infant's trunk was fixed with a broad elastic strap around the torso. Lateral supports maintained the head in the body midline. These supports were adjustable to account for differences in body size. The seat was reclined 72° from the horizontal.

The behavior of each infant was recorded by three Super-VHS video cameras. One camera was in front of the infant at a distance of 2 m, another camera was placed at the infant's left side at a distance of 2 m and the third camera was positioned at a distance of 1 m at 45° from the sagittal plane of the body at the left side. All cameras were linked to separate video recorders, which were synchronized by a time code generator. Video data were collected at 50 Hz. To achieve a reliable assessment of the infants' behavior, all the three video recordings were analyzed. Based on these observations we determined how the infant tried to intercept the ball (i.e., catching style) as well as the amount of (un)successful catches.

2.3. Procedure and design

The infant was presented 15–25 trials (mean 19 ± 3.6). The experimenter classified each trial on-line as either a refusal (no catching attempt) or as a reach. For a catching attempt to be scored, the infant's arm was required to move in the direction of the ball, with the hand terminating within a fist-size distance from the ball. Speed was varied according to a modified staircase method (Adolph, 1995, 1997), which means that speed was varied in relationship to the infant's behavior. During the first trial the ball always moved at 0.3 m/s. The ball speed was increased with 0.3 m/s after two consecutive catching attempts (irrespective of whether the infant contacted the ball) and decreased with 0.2 m/s after a refusal. If a trial could not be classified as a refusal or a catching attempt, the trial was repeated. This procedure continued until the boundary speed was determined, which was defined as the highest ball speed that the infant tried to reach for at least twice, and at which he or she refused to attempt to catch twice at the next increment in speed. The boundary speed thus demarcates the ball speeds that are perceived to be catchable from those speeds that are perceived as non-catchable.

Occasionally, the trials were alternated with short periods in which the infant was allowed to play with the ball to prevent the infant from becoming frustrated or bored. If the infant showed less attention for the ball, the experimenter jingled a little bell behind the ball to direct the infant's attention to the ball.

2.4. Data analysis

The behavior of each infant was scored from videotaped recordings. All trials were categorized as a success (*S*, infant contacted or grasped the object), a failure (*F*, a catching attempt without contact), or a refusal (*R*, no catching attempt). To give insight into the changes with age in infants' catching behavior, the number of catching attempts was determined for each age group. In addition to the boundary speed, the success speed was determined for each infant. The success speed was defined as the highest object speed at which the infant contacted or grasped the ball at least twice and at which the infant failed or refused at the next increment in speed. The difference between boundary and success speed is taken as a first measure for the accuracy of the infants' perception of the affordance of catchability.

The proportion of failures served as a second measure for the accuracy of infant's perception of the ball's catchability, and is independent of object speed. For each infant, it was calculated by dividing the amount of failures by the total amount of trials (i.e., the number of successes plus failures plus refusals). It was assumed that failures reflect inaccurate perception of the ball's catchability (see also Adolph, 1997). A low proportion of failures indicates that the infant took into account his or her catching skill in the perception of catchability.[1]

Finally, for each infant we assessed how he or she attempted to intercept the ball. Each catching attempt was categorized as either right- or left- or two-handed. A two-handed catching attempt was defined as two hands moving simultaneously before the first hand contacts the ball, irrespective of whether they had started to move at the same time.

Chi-square tests, ANOVAs and paired *t*-tests were used to examine dependencies and differences between variables. Tukey HSD post hoc tests were conducted if appropriate.

3. Results

3.1. Number of catching attempts as a function of age

All infants showed attempts to intercept the ball, the amount of which increased with age. This was confirmed with a one-way ANOVA on the number of catching attempts that showed a main effect of age ($F(2, 32) = 2.912$; $p < .005$). Tukey HSD post hoc comparisons pointed out that the 3- to 5-month-old group reached less frequently than the older age groups (Fig. 3).

3.2. Catching performance

3.2.1. Catching style as a function of age

Fig. 4 shows for each age group the distribution of right-, left- and two-handed catching styles. The distribution changed with age ($\chi^2(4, N = 35) = 30.57$; $p < .002$). The young infants mainly used both hands to grasp the ball, whereas the 6- to 7-month-olds have turned to mostly one-handed catching, with a strong preference for right-handed catches. The 8- and 9-month-old infants also caught predominantly with one

[1] There is some ambiguity with respect to the meaning of a refusal. It may not exclusively reflect the perception that a ball cannot be caught, but may also arise from the infant's lack of desire to act. However, it is likely that an infant's desire (or emotions) are not independent from his or her perceptions and actions.

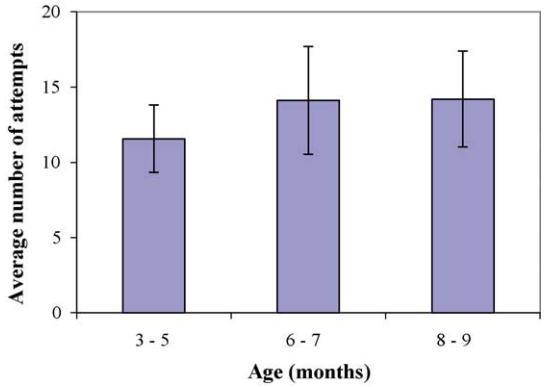

Fig. 3. Mean number of attempts for each age group. Error bars indicate the standard deviation (between-participant variability).

hand, however, the preference for left-handed catching was not very strong in this group. Table 2 reveals that the individual catching styles reflect the observed group averages.

3.2.2. Dependency of catching style on ball speed and age

Fig. 5 illustrates a predominance of right-handed catching for the fastest ball speeds. By contrast, for the lower ball speeds, which afford infants more time to act, no clear preference was found. A chi-square test yielded a significant difference between the distribution of catching styles when the object velocities were grouped as low (0.3–0.6 m/s), medium (0.7–1.0 m/s) and high (1.1–1.5 m/s) ($\chi^2(4, N = 35) = 16.53$; $p < .01$).

Fig. 6 shows how the relation between catching style and ball speed interacted with age. The predominant style of catching by the youngest infants appears to be two-handed, irrespective of ball speed. At the age of 6–7 months, however, an effect of approach speed appears to occur; low object speeds induced all the catching styles, whereas the fastest speeds induced a predominance of right-handed catching. The

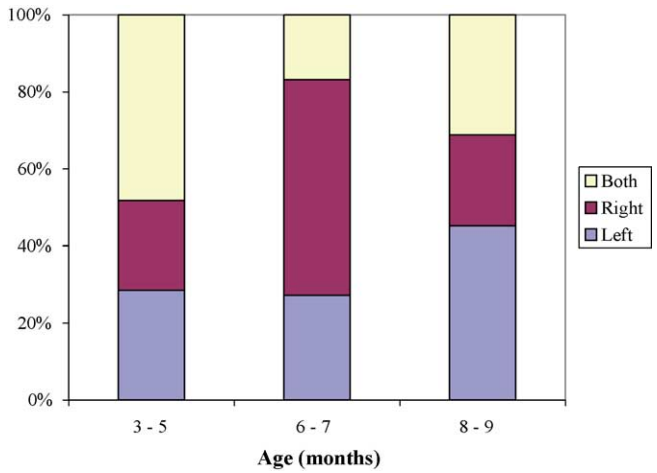

Fig. 4. The distribution of the catching styles for each age group.

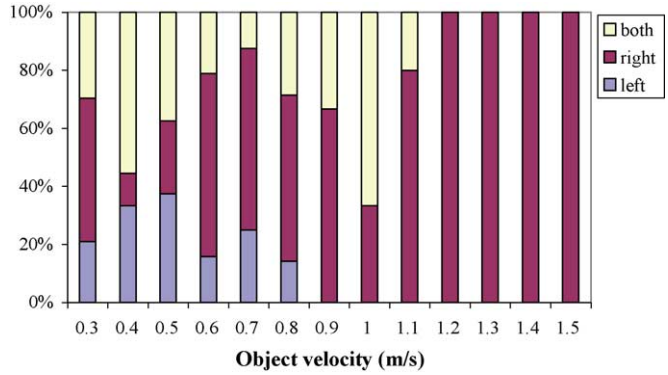

Fig. 5. The distribution of catching styles for each approach velocity of the ball.

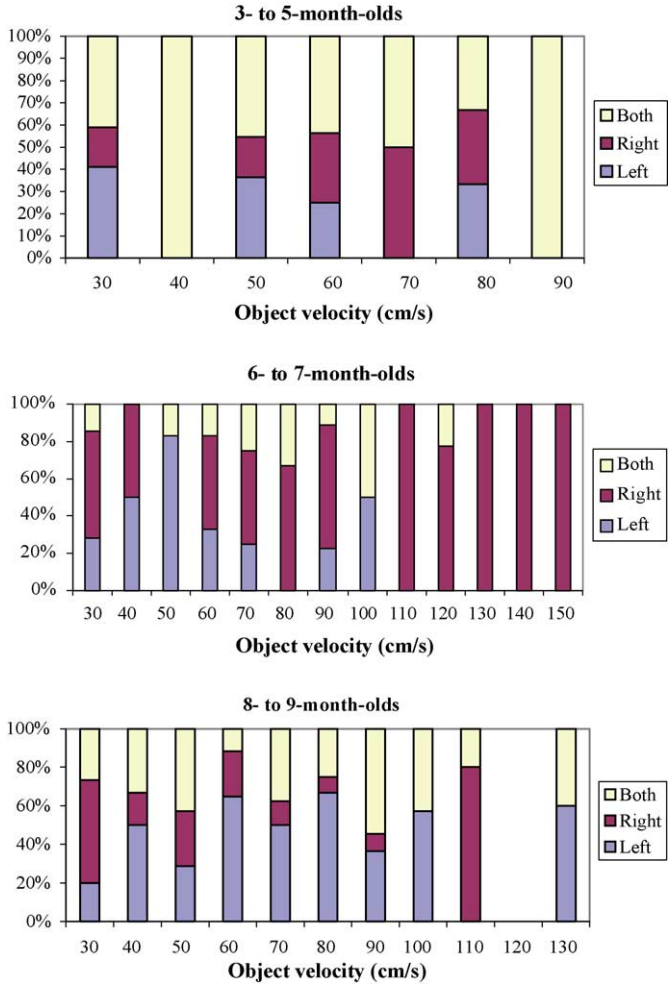

Fig. 6. The distribution of catching styles for each age group and ball speed.

Table 2
For each infant the age, the amount of displayed catching styles and the individual distribution between the right-, left- and two-handed catching style

Infant	Age (months)	Variety catching styles	Proportion left	Proportion right	Proportion both
Ma	3	3	0.33	0.33	0.33
Pu	3	3	0.33	0.33	0.33
Ed	3	2	0.33	0	0.67
Mr	3	3	0.33	0.33	0.33
Ru	3	2	0.33	0	0.67
Bi	4	2	0.33	0	0.67
Ce	4	2	0	0.20	0.80
Li	4	2	0.36	0	0.64
Mt	4	3	0.57	0.14	0.29
Wo	4	3	0.60	0.20	0.20
Lo	5	2	0.36	0	0.64
Vr	5	2	0	0.38	0.62
Rb	5	3	0.17	0.5	0.33
Vk	5	3	0.25	0.56	0.19
Ta	5	2	0	0.46	0.54
Sf	6	3	0.25	0.56	0.19
Md	6	3	0.25	0.44	0.31
Ka	6	3	0.38	0.38	0.25
Ha	6	1	0	1.00	0
Sh	6	3	0.43	0.29	0.29
Jo	7	2	0.20	0.80	0
Is	7	1	0	1.00	0
Pe	7	3	0.22	0.44	0.33
Im	7	3	0.25	0.50	0.25
Vg	7	2	0.80	0.20	0
Lr	8	2	0	0.44	0.56
Te	8	3	0.33	0.08	0.58
Mi	8	3	0.29	0.14	0.57
Yo	8	3	0.71	0.14	0.14
Ya	8	3	0.75	0.13	0.13
Si	9	2	0.75	0.25	0
Ks	9	3	0.34	0.03	0.62
Sa	9	2	0.89	0.11	0
Tr	9	2	0.44	0	0.56
Vj	9	1	0	1.00	0

right hand preference seems to have disappeared in the 8- and 9-month-olds. They do show instead a frequent use of the left hand, irrespective of object speed. Some care has to be taken when interpreting these findings because the low number of observations make it difficult to assess the reliability of these interpretations.

In sum, we tentatively conclude that the catching styles were not evenly distributed over age. Each age group showed their own way to cope with the tightened temporal constraints when the object approached faster. The question now is whether there is a relation with the accuracy by which infants perceived the

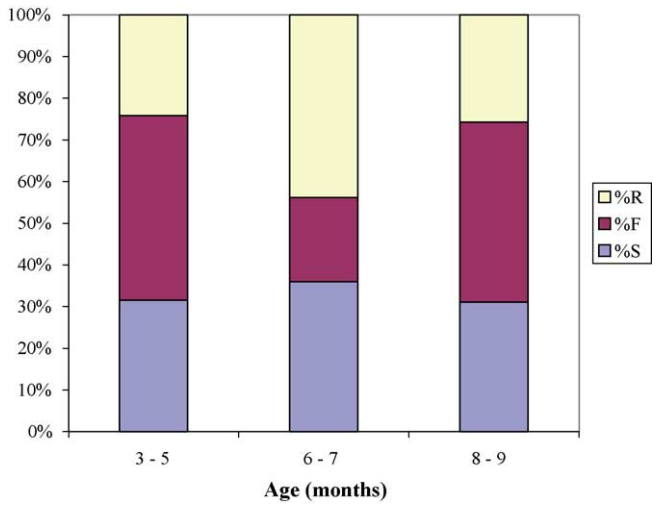

Fig. 7. For each age group, the amount of successes (*S*), failures (*F*) and refusals (*R*) converted into percentages of the total amount of trials.

ball's catchability. First, the results with respect to the number of successful catches, failures and refusals are presented.

3.3. Perception of catchability

3.3.1. Distribution of success, failure and refusal as a function of age

A chi-square test on the number of successes, failures and refusals for each age group yielded a significant effect ($\chi^2(4, N = 35) = 21.01$; $p < .002$). As can be seen from Fig. 7, which shows the percentages of successes, failures and refusals, at 6- to 7-months' infants exhibited fewer failures but not more successes than at the other ages. The proportion of refusals is relatively high at this age, which is indicative of a more appropriate match between the decisions whether to catch and the probability of success of the catch.

The higher incidence of refusals combined with a drop in the proportion of failures at 6–7 months of age is indicative of an improvement in the accuracy of the perception of whether objects that move at different speeds can be caught or not (73% of the catching attempts led to contact). Both younger and older infants' perception of the ball's catchability was less accurate (50 and 42% successful catching attempts, respectively). A one-way ANOVA revealed an age effect on the proportion of failures ($F(2, 32) = 3.661$; $p < .05$). Tukey HSD post hoc comparisons indicated that only the difference between the (6–7) and the (8–9)-month-old infants was significant.

3.3.2. Boundary and success speeds

Fig. 8a shows for each age group the boundary and success speeds. Both the highest ball speed at which infants consistently attempted to catch (i.e., boundary speed) and the highest ball speed that the infants either touched or grasped (i.e., success speed) increased with age. One-way ANOVAs for group on boundary ($F(2, 32) = 15.911$; $p < .001$) and success speed ($F(2, 32) = 10.521$; $p < .001$) confirmed these observations. Tukey HSD post hoc comparisons indicated for both the boundary and success speeds

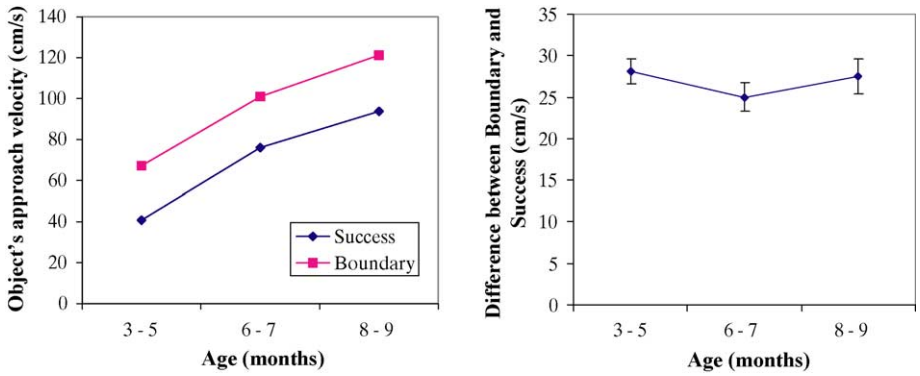

Fig. 8. The averaged boundary and success speed as a function of age (a) and for each age group the discrepancy between boundary and success speed (b). Error bars indicate between-participant variability.

significant increments after 6–7 months of age. Fig. 8b shows that the difference between the boundary and success speed fluctuates around 0.275 m/s. One-way ANOVA for group on the difference between boundary and success speed yielded no significant effect of age. In summary, only the proportion of failures (Section 3.3.1) seems to suggest a (temporal) improvement of the perception of catchability. Although the 6- to 7-month-olds demonstrate a slightly better perception of the ball's catchability than the infants in the younger and older groups, it was still not completely accurate, as indicated by the occurrence of failures and the fact that boundary speed was not equal to the success speed.

3.4. Catching style and perception of catchability

We have seen that the 6- to 7-month-old infants showed the strongest preference for right-handed catching (Fig. 4; Table 2) and seemed to perceive catchability most accurately (Fig. 7). This suggests that

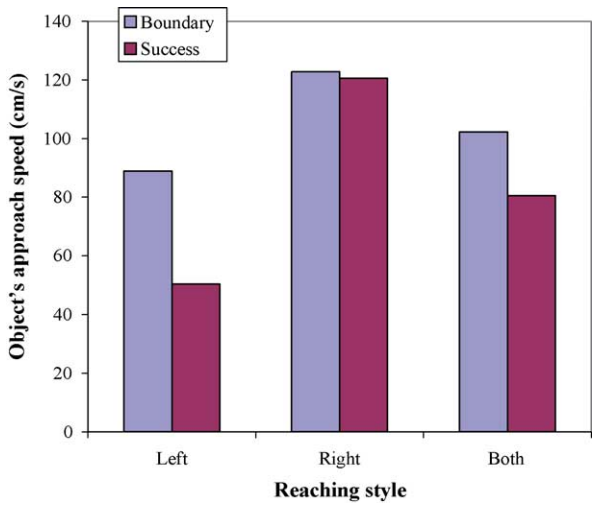

Fig. 9. For each catching style the averaged boundary and success speed.

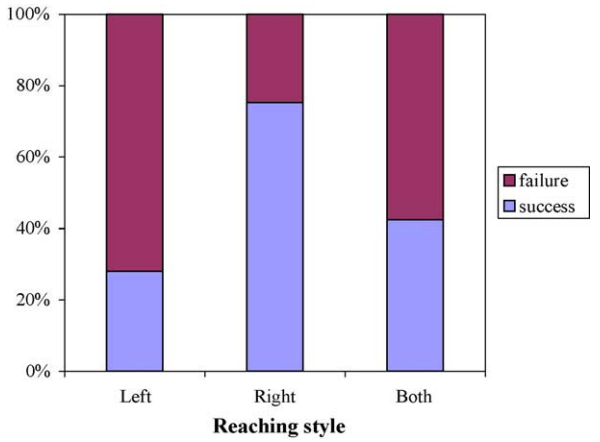

Fig. 10. For each catching style the percentages of successes and failures.

the catching style that is adopted constrains the accuracy of the perception of catchability. Therefore, we established for each catching style the success and boundary speeds (Fig. 9) and the outcome of the catching attempts (Fig. 10).

Fig. 9 shows that when the infants caught with their right hand, their perceptual judgments of the ball's catchability was matched quite accurately to their catching skills; the discrepancy between boundary and success speeds almost being zero. Paired sample *t*-tests were used to test the null hypothesis that the boundary and success speeds were not different. This null hypothesis can be rejected in the case of left-handed ($t(54) = 2.55$; $p < .01$) and bimanual catches ($t(56) = 1.80$; $p < .05$). Only when infants caught right-handed no significant discrepancy could be found between boundary and success speed ($t(56) = 0.13$; n.s.). In addition, right-handed catching clearly resulted in more successful catches (Fig. 10). Chi-square on the amount of successes and failures per catching style confirmed this ($\chi^2(2, N = 35) = 36.773$; $p < .002$).

4. Discussion

The present study sought to uncover how the confluence of intrinsic and extrinsic constraints shape the early development of catching, and how this impinges on the perception of whether or not a moving object affords catching. Infants between 3 and 9 months of age with different reaching preferences were presented with balls approaching from their left side with different speeds. We explored how the interaction between infants' intrinsic constraints which gave rise to for example preferred catching tendencies and the extrinsic constraints imposed by object speed induces age-related differences in catching behavior and age-related differences in the perception of what action a moving object affords.

Even the poorly developed catching behavior of the 3- to 5-month-olds showed signs of a tight interaction between intrinsic and extrinsic constraints. The youngest infants displayed a strong preference for trying to intercept the moving ball with both hands. It seems reasonable to suggest that this predominance of bimanual catching reflects the infants' intrinsic constraints (Corbetta & Thelen, 1996; Thelen et al., 1993). At this age infants show their first reaches, which are often but not always two handed, even when they reach for relatively small balls. Also, the fact that objects are often presented at the infants' body

midline is thought to result in the high proportion of observed bimanual reaches (Van Hof et al., 2002). In the present experiment, the interception area is smallest when trying to seize the ball with both hands. With this catching style infants cannot satisfy the temporal constraints imposed by ball speed. Therefore, it may have been these rigorous temporal constraints that withheld the 3- to 5-month-olds from reaching for balls that approached with high speed. Moreover, the temporal constraints may also have contributed to the low proportion of successful catching attempts for the high ball speeds. Nonetheless, the fact that 3- to 5-month-olds are still exploring their arm movements (e.g., Von Hofsten, 1991) is perhaps the most important cause of the high proportion of futile attempts to intercept the ball together with a low proportion of refusals. Yet again, the degree to which control of arm movements is mastered appears an important constraint in the accuracy of perceiving whether a moving object can be caught: the poor catching skill of the 3- to 5-month-olds goes together with an inaccurate perception of what action a moving object affords (see also Van Hof et al., 2005). In sum, the poorly developed catching behavior of the 3- to 5-month-old infants first and foremost reflects intrinsic constraints, and is only slightly affected by external constraints like ball speed. Together, this resulted in inaccurate perception of catchability.

The interaction between intrinsic and extrinsic constraints appears to have changed by the time infants are 6–7 months of age. Infants now attempt to catch predominantly with the right hand, which is the hand contralateral to the approaching ball. The number of bimanual attempts have decreased dramatically. The incidence of one-handed and two-handed reaches fluctuates during the first year (Corbetta & Thelen, 1996). Several authors have assumed that as a concomitant of an increase in postural control (i.e., 6- to 8-month-old infants are beginning to sit independently) two-handed arm movements are more frequently alternated by one-handed ones (e.g., Rochat, 1992). The increased postural control is thought to free the infant from the burden to maintain balance by moving the two arms symmetrically. Thus, 6- to 7-month-old infants can use both the left and the right hand to intercept the approaching ball. The finding that the 6- to 7-month-olds in the present study predominantly used the right hand to attempt to catch for the ball, in particular for the highest ball speeds, strongly suggests that at this age infants have the movement possibilities to respond effectively to the extrinsic constraint imposed by object speed. The time available to prepare and execute the catch is largest when the infants try to seize the ball with the right hand. In other words, right-handed catches are most effective in granting the possibility to intercept fast moving balls. In general, a right-handed catching style was accompanied by a lower proportion of failures to intercept the ball (Fig. 10). This was true for the majority of 6- and 7-month-old infants. Nevertheless, in contrast to our earlier observations for frontally approaching objects (Van Hof et al., 2005), which hardly allow catching styles other than right-handed attempts, the perception of catchability was still not very accurate (Figs. 7 and 8). In sum, at 6–7 months of age infants' movement potential has increased, which allows them to deal with the extrinsic constraints imposed by object speed. Right-handed catches reduce the temporal constraints and make it possible to intercept even fast approaching objects. This relatively stable catching pattern (i.e., infants still could, and did, use alternative catching styles) was associated with an improvement in the perception of catchability, although perception was still not very accurate.

The catching behavior of 8- and 9-month-old infants indicates yet again a changed interaction of intrinsic and extrinsic constraints. The 8- and 9-month-olds showed a relatively low proportion of successful reaches. A significant large amount of balls were missed, and at the same time only a few balls were refused. Hence, the 8- and 9-month-olds frequently misperceived what ball speed could be dealt with. The decrement in catching performance coincided with the catching styles being distributed in an even way. There was no predominant catching style, although compared to the 6- and 7-month-old infants the 8- and 9-month-olds showed more left-handed reaches. A similar change, an increasing proportion

of ipsilateral reaches with age, was observed by Von Hofsten (1980). Newman, Atkinson, and Braddick (2001) have used the term "compulsively" for the catching behavior of infants of this age, in other words, when presented an object infants seem trying to grasp it as soon as possible. Even if this goes at the expense of the time available to prepare and execute the grasping movement, which is the case for the 8- to 9-month-olds in the present study. The need to satisfy the temporal constraints has become subservient as is manifested by the observation that left-handed reaches are elicited independent of ball speed, suggesting flexible constraint hierarchies in infants (see also Rosenbaum, Loukopoulos, Meulenbreuk, Vaughan, & Engelbrecht, 1995). At 8–9 months, as compared to the 6-and 7-month-olds, it seems that the desire to get the ball as soon as possible is prevalent, and that this is detrimental to the accuracy of perceiving whether a ball can be caught.

In sum, the present study shows the waxing and waning of different types of constraints impinging on catching behavior during the first 9 months after birth. More specifically, it is the intertwining of extrinsic constraints (i.e., imposed by the size of the interception area and the ball's speed) and intrinsic constraints (which give rise to catching preferences and the inclination to reach) that induces a change in catching style and success with age. Multiple constraints are involved, that is, different aged infants with different catching preferences appear to feel the need to satisfy different constraints. This exploration of the hierarchy in extrinsic and intrinsic constraints is reflected in the observation that each age group appears to have selected the catching style that would be the most promising for what constraint they want to satisfy. That is, it is the interaction between extrinsic and intrinsic constraints that determines whether two-handed, right-handed or left-handed reaches are most appropriate.

Moreover, the present findings together with previous observations (Van Hof et al., 2005) suggest that for the infant to accurately perceive whether a moving object can be caught, not only a certain degree of control of the catch is required, but also a certain stability or prevalence of the task solution (i.e., catching style). Three- to five-month-old infants do not have sufficient control over their arm movements yet, perhaps because they tend to use less appropriate visual distance-specific information to control catching (see Van Hof et al., 2005). This coincides with an inaccurate perceptual differentiation between balls that can be caught and balls that cannot be caught. From 6–7 months onwards, infants have improved control over their arm movements, probably because they now use visual information that is time-specific (Van Hof et al., 2005). This would be associated with a dramatic improvement in the accuracy of perceiving whether a ball can be caught if a particular catching style would consistently be used; such as the right-handed catches for frontally approaching balls (Van Hof et al., 2005) and the right-handed catches in the present study. If, however, infants use several catching styles interchangeably, as was the case for the 8- and 9-month-olds in the present study, the accuracy of perceiving catchability diminishes.

Thus, learning to perceive which action opportunities the environment offers heavily leans on the development of action. As the development of action is governed both by extrinsic constraints and the infant's own set of constraints, age-related changes in the perception of affordances should be understood as accomplished by the ever changing interaction between the infant's preferred movement tendencies and task circumstances.

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